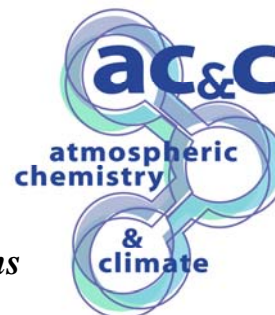**Joint HTAP/AC&C Workshop**
11-13 June 2008
Washington, DC

Summary of Discussions & Decisions
Regarding the IGAC/SPARC
Atmospheric Chemistry & Climate Initiative

Overview of "Atmospheric Chemistry & Climate" Activity (AC&C)
Phil Rasch

First proposed as a joint IGAC/SPARC (WCRP's "Stratospheric Processes And their Role in Climate" project) initiative in March 2006.

Summer/Fall, 2007:
- AC&C Activity plans developed
- AC&C liaisons initiate coordination with AeroCom, CCMVal, HTAP

March 2008: Conference call of AC&C Steering Committee
- Review/discussion of activity plans (for 3 of 4 activities)
- Agreement to arrive at workshop with detailed model run plans & example model run output

The Path Forward:
- June, 2008: 2nd AC&C Workshop, joint w/ HTAP (Washington, D.C.)
- Finalize activity model runs with engagement of all model groups, in close coordination with HTAP "next phase" plans
- Mid-2008 to 2009: Model runs, publications
- Late 2009: Models are "frozen" for next IPCC Assessment (IPCC report now confirmed for 2013)

AC&C activities aim to contribute directly to IPCC AR5 & next Ozone Assessment and to be tightly coordinated with the activities of HTAP, AeroCom & CCMVal.

Four activities identified for AC&C Phase I:

Activity 1: Hindcast Experiments
Leads: Peter Hess, Jennifer Logan, Oliver Wild, Michael Prather

Activity 2: What controls the vertical distribution of species. Step 1: Focus on 5km-tropopause
Leads : Joyce Penner, Jose Rodriguez, Celine Mari

Activity 3: Cloud-chemical interactions
Lead: Thanos Nenes

Activity 4: Future Scenarios: Sensitivities & Uncertainties
Leads: Drew Shindell, JF Lamarque, Michael Schulz

→ Activities 1, 2 and 4 have commonalities with HTAP and will be discussed at this meeting.

Goals for this meeting:
- Firm up definition and implementation of Activities 1, 2 & 4
- Reconfirm and/or identify new leads/committee for Activities
- Experiment/Simulations defined
- Data needed identified
- Start list on output diagnostics to support evaluation
- Expectations for progress (e.g. milestones, timeline)
- Resolve our need for a model archive/data center
  - We propose use of the TFHTAP facility developed by Martin Shultz in Jülich
    - ~ Data Archive
    - ~ Wiki
- Opportunity/need for next meeting?

Note: Sessions on "Atmospheric Chemistry & Climate" are being held for the last two days of the SPARC Conference (Bolgona, Italy; September 1-5, 2008) and the first two days of the IGAC Conference (Annecy, France; 7-12 September 2008). It is also planned to have an evening meeting during the IGAC conference to introduce AC&C to a broader community.

AC&C Activity 1: Hindcast Experiments

Overview of Hindcast Experiments
Peter Hess

Objective: Evaluate the performance of global chemistry-transport models (CTMs) in preparation for their use in future climate projections.

- Test the capability of current atmospheric chemistry models to integrate over the variations and trends in circulation and climate, in emissions, and in chemical feedbacks that control atmospheric composition.
- Quantify and derive objective measures of uncertainty when global chemistry models are used in climate system models to project conditions of the 21st century

Experimental Approach
- Use the past few decades for which we have observations of trends and variability in atmospheric composition.
- Focus on large space (1000+ km) and time scales (multi-year to decadal variability) that are essential in projecting 21st century change, and that effectively integrate over many atmospheric processes.
- Take an integrative approach and not focus on process validation, which will be examined in other activities.

Four separate but inter-related hindcasts planned:

Simple tracers (CFCs and N_2O) – *Cynthia Nevison, Peter Hess, Michael Prather, and Natalie Mahowald*

Aerosols – *Mian Chin & Michael Schulz*

Ozone variability (including simulations of OH) – *Jennifer Logan, Peter Hess & Oliver Wild*

Methane variability – *Arlene Fiore, Frank Dentener, Peter Hess & Isabelle Bey*

Each hindcast experiment defined by:
- a multi-year series (post-1980) of measurements of atmospheric trace species.
- a clear objective grading criteria for evaluating model success.
- a set of required diagnostics to facilitate model comparison and evaluation.
- multi-year external forcings (e.g., emissions) needed to drive the simulations.
- guidelines on the types of chemical models and meteorological fields that can usefully participate.

Notes that these runs can be combined as appropriate where models have this capability, assuming the same emissions databases are used (e.g. IPCC and HTAP).

Options for timeline of runs:
→ For all Aerosol Hindcast runs, have suite of Options, in terms of time over which to do runs. For Ozone and Methane Hindcasts, still undecided but Options 2, 3 and 4 are being considered:

Option 1 (Aerosols: satellite era)
- 1980-2009 (~30 continuous years)

Option 2 (Ozone: large changes in lower strat ozone)
-   1990-2009 (~20 continuous years)
Option 3 (Aerosols : EOS & A-train era)
-   2000-2009 (~10 continuous years)
Option 4 (HTAP SR1/SR6 & Aerosols: CALIPSO/A-Train)
-   2001 & 2007 only

→ Participating groups are asked to choose one or more of these periods according to their computing possibilities
→ Requirements: global models using reanalyzed or assimilated meteorological fields (preferred), but global models driven by observed SSTs also accepted.
→ All aerosol hindcast model runs are additionally encouraged to add a one year simulation (with appropriate spin-up) for preindustrial conditions of aerosol emissions, corresponding to the year 1860 in supplement to any of these options.

AC&C Activity 1: Simple Tracers Hindcast Runs
Cynthia Nevison, Peter Hess, Michael Prather, and Natalie Mahowald

Goals:
➢ Match the trends and variability of the nearly-inert trace gases CFCs (CFC-11, CFC12) and N_2O as measured by stations of the ALE/GAGE network.
➢ Quantify importance of:
    o   changing emissions
    o   tropospheric meteorology
    o   stratosphere-troposphere exchange variability.
➢ Test STE fluxes of O_3, N2O, CFCs, …
➢ Test hemispheric and intra-hemispheric mixing
➢ (Implied) test of vertical turnover of troposphere

Science basis for interest:
•   Discrepancy between atmospheric transport model (MATCH) results (without stratospheric sink) and observed atmospheric N_2O seasonal cycles
•   Correlated interannual Variability observed for N_2O, CFCs but also is not captured by MATCH run
    ➢ Appears related to need to represent stratospheric processes (large-scale circulation; stratospheric sink)
•   Observations exist that allow for testing of model performance in reproducing CFC, N_2O trends and seasonal- to inter-annual variability.
•   Models can be used to distinguish between seasonal cycles due to stratospheric influence vs. tropospheric transport of recent emissions

Approach:
•   Use Emission-Based Forcing for CFC, N_2O tracers:
    o   CFCs: Spatial distribution and temporal trends
    o N_2O: Spatial distribution from a posteriori inversion results

- Compare model results to seasonal, spatial and inter-annual variability observed by AGAGE, NOAA HATS & CCGG
- Distinguish between seasonal cycles due to stratospheric influence vs. tropospheric transport of recent emissions

→ Urge all AC&C Activity 1 (Hindcast) CH_4 and O_3 models to participate.
→ Urge all AC&C Activity 1 (Hindcast) Aerosol models to at least do SF6, which will provide test of pollutant flow to Arctic

Gas	Observ. Data	Emission grid	Total emissions	Diagnostics
N_2O	AGAGE+NOAA HATS surf sites, since 1980, NOAA CCGG sites since 1997	anthrop+natural, fixed over 25 yr, seasonal	scale to fit obs & loss ("box inverse")	monthly mean 3D, daily surf?
CFC-11	AGAGE+NOAA surf sites, since 1980	Industrial shift to landfill/banks	scale to fit obs & loss ("box inverse")	monthly mean 3D, daily surf?
CFC-12	AGAGE+NOAA surf sites, since 1980	Industrial shift to landfill/banks	scale to fit obs & loss ("box inverse")	monthly mean 3D, daily surf?
SF_6	NOAA CCGG surf sites, since 1997	industrial/elect.	scale to fit obs ("box inverse")	monthly mean 3D, daily surf?
O_3	---	---	---	STE flux (lat x month?)
HFC-134a?				

AC&C Activity 1: Aerosol Hindcast Experiments
Mian Chin & Michael Schulz

Goals: Better understanding of:
- regional and global satellite observed trends in AOD
- regional differences in sulfate and black carbon deposition from the Arctic to the Alps
- temporal trends in aerosol concentration, composition, optical properties and deposition
- emission trends of primary aerosols and aerosol precursor gases
- the impact of changing meteorology (& natural emissions) vs changing anthropogenic emissions on aerosol trends
- dimming and brightening trends observed by surface radiation networks
- the evolution of the anthropogenic aerosols perturbation of the Earth radiative balance

➢ To be run as part of AeroCom Project

Background:
- Observations of aerosol AOD variations come from:
    - Satellite records (starting with AVHRR in 1980; continuing with e.g. MODIS & MISR)
        - Issue of how well long-term trends can be caputured
    - Surface observational networks monitoring radiative fluxes
        - Local, not global, but records run back as far as 1950, 1960.
        - "Supersites" provide comprehensive information on surface-level aerosol physical/optical/chemical properties, which can be used to test the models
    - Aircraft and other intensive field campaigns
        - Not useful for determining trends, but for testing how representative models are during "snapshot" periods

RUNS:

→ "HCA-0" :
Can aerosol models reproduce 1980 to present:
- *Trends?*
- *Variability?*
- *spatial patterns?*
- *(also, look at how forcing/mass – efficiency – changes with time, which is a function of meteorology)*
- Hindcast simulation with time varying emissions and reanalyzed meteorological fields. Participants use own choice of emissions.
- Expected to be run by a few model groups early on to test set-up, especially when IPCC emissions are yet not available. Simulation should be complementary to HCA-IPCC simulations, expected to be run by all groups.

→ "HCA-IPCC":
Can aerosol models reproduce 1980 to present:
- *Trends?*
- *Variability?*
- *spatial patterns?*
- *(also, look at how forcing/mass – efficiency – changes with time, which is a function of meteorology)*
- As with HC, but models all run with IPCC emissions (available Oct 2008).
- Option: use dust and sea salt emissions as provided from a model that generates these based on meteorology, etc.
- Expected to be run by most/all model groups doing Aerosol Hindcast runs.

→ "HCA-FX":
What is the influence of meteorology + natural emissions?
Models all run with same anthropogenic emissions, which do not change with year. (e.g. use 2001 emissions for all years of run HCA-IPCC).

Note: prescribed anthropogenic emissions includes anthropogenic biomass burning. Will need to include caveat with runs that anthro. biomass burning has very large interannual variability, so emissions selected are not necessarily "representative" for any given year and model results might change in very high/low anthro biomass burning year.

→ "HCA-MET":
How do aerosols interact with meteorology?
- GCMs: fix SSTs and let meteorology and hence transport and removal evolve under the impact of aerosol direct + indirect effect. This differs from "HCA-IPCC" in that the GCMs in "HCA-IPCC" would be nudged to match observed meteorology, whereas in "HCA-MET", the GCMs would be forced only by SST's.

➢ Data from all of these runs would be saved on the AeroCom data server

OBSERVATIONS:
- Fairly good idea of what is available in terms of satellite data and ground-based long-term monitoring stations.
- Need more work on what is available for aircraft campaigns. First-pass list:
    - INDOEX
    - ACE-Asia/TRACE-P
    - INTEX-B/MILAGRO
    - ICARTT
    - POLARCAT/ARCTAS
    - (N-)AMMA
    → use model to follow flight tracks, then average over, e.g., altitude bins & compare to mean values from measurements.
- Lidar data:
    - Compare 180-backscatter (not extinction)
    - CALIPSO + select 10 sites (see EARLINET (Europe), ADNET (Asia), REALM?(U.S.)) and produce diagnostics for these

TIMELINE:

Summer 2008:
1. Fine-tune run specifics, in particular diagnostics.
2. Special attention to what observations are available and therefore what parameters should be save and where/when (in models).
3. Survey modeling groups for what runs/options they would do & how many would use prescribed dust/sea salt for Run "HCA-0" & "HCA-IPCC".

October 2008: Will have IPCC emissions; commence runs.

AC&C Activity 1: Ozone Hindcast Runs
Jennifer Logan, Peter Hess, Oliver Wild
AC&C Activity 1: Methane Hindcast Runs
Arlene Fiore, Frank Dentener, Peter Hess, Isabelle Bey

Note: Ozone and Methane Hindcasts are linked, and so are presented here together.

Ozone Hindcast

Ozone Background
- Major factors driving changes in tropospheric ozone:
  - trends in precursor emissions, especially NOx
    - increases in Asia, increases then decreases in Europe, U.S.
  - trends in methane
  - interannual variability in biomass burning
  - changes in ozone in the lower stratosphere (LS)
  - dynamical variability, e.g., AO, ENSO, STE, ..
  - climate change, temp. trends etc
- Reasons for ozone hindcasts:
  - Necessary for methane hindcasts
  - Large changes over the last few decades in:
    - STE
    - Emissions
    - El Nino, AO/NAO
    - Climate
      - temperature has increased by approximately 0.6K since 1960
      - precipitable water vapor has increased by approximately 0.4mm per decade between 1998 and 2003
- ~13 models interested in doing ozone hindcasts
- Some models in CCM-Val are planning similar simulations already.

Ozone Datasets for comparison to models :
- CO - NOAA/GMD surface stations, MOZAIC aircraft data, MOPITT, …..
- NO_2 – GOME, SCIAMACHY, OMI columns – issues with different retrieved products
- Ozone – surface stations, sondes, MOZAIC, TCO products, satellite data for the LS (SAGE, Aura MLS)
  - Focus here on data above the surface (not that there are no issues with surface data)
  - Europe has the most long-term records from sondes
  - 3 profiles/week at 3 sites, two since 1960s
  - Weekly data at several other sites
  - Also frequent ascents and descent of MOZAIC aircraft, since late 1994

<u>Methane Hindcast</u>
- Goal: Match the observed methane trends and variability.
- Quantify:
  - ➢ the importance of changing anthropogenic and natural emissions
  - ➢ the importance of OH variations
- Procedure: Use OH fields from the ozone hindcast in an inverse modeling calculation for methane emissions – reconcile top-down and bottom-up emission estimates.

<u>Methane Background & Framing Issues</u>
- Total CH_4 source: ~600 Tg yr-1, ~60% anthropogenic [IPCC AR-4]
- >25% uncertainty in present-day CH_4 sources; much larger uncertainty in contributions of individual sectors
- Methane sink (OH) also ~30% uncertain
- Framing questions:
  - o Why have methane concentrations leveled off?
    - ▪ Model studies indicate different drivers for observed decadal trends
  - o How well do we understand inter-annual variability?
    - ▪ e.g. Major driver of '97-'98 anomaly? (biomass burning? wetland emissions?)
  - o Can we begin to reconcile conclusions from top-down and bottom-up approaches?

An idea put forward was that the methane work under AC&C should be done jointly with TRANSCOM Activity, to address the issue of reconciling top-down and bottom-up approaches.
> Forward model hindcast, including sources of OH variability: 1980-present
- ozone (and aerosol) precursor emissions (anth., biomass burning, biogenic, lightning)
- methane specified to observed values (lower boundary or fixed abundances)
- stratospheric ozone columns specified (unless simulated in the model)
- meteorology (reanalysis and/or GCM driven by observed SSTs)
> Forward model output available for input to methane inversions:
- Interannually varying monthly mean OH fields (ensemble mean; uncertainty)
- Archived methane loss by tropospheric OH (also to stratosphere / soils) = implied global emissions, may help with a priori error estimates
> Multi-year inversion modeling for methane:
- Interannually varying monthly mean OH fields (forward model ensemble mean)
- Constant OH (multi-year forward model ensemble mean?)
- Coordinate with HYMN (Hydrogen, Methane and Nitrous oxide: Trend variability, budgets and interactions with the biosphere)

TO BE DONE:

Ozone Hindcasts:
- ➢ Define the forcings:
    - o The stratosphere:
        - ▪ Total O_3 dataset for use in photolysis calculation?
        - ▪ For models without stratospheric chemistry, stratospheric ozone variations?
        - ▪ Volcanic forcing?
    - o Emissions:
        - ▪ Common emission dataset?
        - ▪ But which one?
        - ▪ Will common emissions adversely affect CH_4 inversions?
- ➢ Define the observations
    - o Pick a few observational datasets which we want to match:
        - ▪ Long term
        - ▪ Span as many locations as possible
        - ▪ Trusted record
    - o We don't need to match every dataset, but need a few crucial and revealing datasets we want to match.
    - o Do appropriate datasets exist? Over what time spans?
- ➢ Define the time period:
    - o 1980-present;
    - o 1990-present; or
    - o 2000-present
        - → can we justify running 1980-present?
        - → Do we have appropriate datasets for testing?
        - → Do we know appropriate forcings?
        - → What do we want for the methane runs?
- ➢ Define the diagnostics
    - o HTAP and AEROCOM diagnostics
    - o Temporal frequency depends on questions and observations
    - o Special diagnostics to define key processes (e.g., stratospheric tracer)

Methane Hindcasts:

- ➢ Interest is high
- ➢ Need more discussions with the inverse community
- ➢ Discussion postponed at this meeting
    - o Simulations can only begin after the ozone hindcasts
- ➢ Observations: NOAA cooperative network

AC&C Activity 2: Controls on Vertical Distribution of Species
Step 1: What controls distribution 5km to tropopause
Jose Rodriguez & Joyce Penner

Processes:
- Advection by large-scale winds
- Convection
- Wet scavenging
- Dry Deposition
- Stratosphere-Troposphere Exchange (CCMval, SPARC)
- Chemistry
- In situ production of ozone precursors

→ Start off looking at *convection* and *scavenging* processes, as these are the most uncertain and biggest "knobs" in the models, in particular when looking at UT.

Convection Runs:

Understand variability within models resulting from convective parameterizations, i.e.:
- Is it convergence and divergence (met fields/large scale circulation) that are driving variations, or convective parameterizations in the model?
- Which component of the model needs the most focus to understand what determines deep convective transport?

Do a "tightened up" set of HTAP TP1x runs, with the following variations:
- With tracers representing different species lifetimes (need one w/ a 5 day lifetime)
- With no convective transport (have convection, but tracers don't follow convection)
- With range of convective transport → look at these first two runs and see what kind of range we get. Folks tweak models in 3rd set of runs based on range of outcomes of first run. {Note: runs in Mark Lawrence group found linear response 1-10% decrease in mass flux, but not between 10% reduction and turning it off}.
- (Possible next set of runs would be to turn off turbulent transport processes)

→ Comparison with data:
- SO_2 sources w/ a 5 day lifetime. Can use aircraft data.
- one with a marine source and one with a continental source?
- Propane? Issue is that the emissions distribution is pretty good (forecasts v sobs is ~0.9). emissions are off by a factor of 3, but *correlations* are good. This is similar to CO (similar sources) but 3-10 day lifetime.

→ Focus: Northern mid-latitudes because this is where measurements are. In South, it would be biomass burning.

<u>Scavenging Runs</u>:

➢ Model scavenging schemes are much more diverse than are their convective schemes, so this will be more exploratory (to start) than Convection runs.

➢ Models impose perturbations to processes that drive scavenging.
- key is to define range of "tweaks"
- Stage 1:
  - o have an exploratory set of exercises that will define next phase
  - o 2-3 groups to exploratory runs and look at them together
  - o then engage larger community based on spread/ranges given in first set of runs (range w/in which to perturb processes)
- Nitric acid and sulfate-like tracers and diagnose how different processes control budgets of these things.
- Use budgets as a diagnostic to determine how much scavenging is via:
  - o washout vs. rainout
  - o convective updraft vs. large-scale circulation
  - o ice nucleation vs. warm-phase
  - o etc.

<u>Open Issues</u>:
- Details of runs
- Emissions to use
- Time periods of runs
- Need to link to:
  - SCOUT activities
  - CRM runs
    - o Event simulations from TROICINOX, AMMA, TC4, etc.
    - o compare to same statistics from global models
  - HTAP TP runs & SR runs (in terms of convective mass fluxes)

AC&C Activity 4: Future Scenarios
Drew Shindell

→ Trying to build on what will be done for AR5 simulations, so will not involve additional model runs. Instead, will define diagnostics to be saved common to all models.

→ For AR4, common diagnostics were not saved

→ Note that some models will run chemistry/aerosols off-line, so will need to do this first and then provide output to GCMs. Some will do fully coupled chemistry, with atmosphere and ocean.

→ Scientific questions:
- Radiative forcing, atmospheric heating & climate response
- STE (relative roles of ozone recovery and circulation change)

→ Diagnostics:
- Extending PCMDI-style archive to composition ("AC&C-MIP")
- Produce a 4D climatology of gases & aerosols for climate modeling groups
    - Issues:
        - Average of all, multiple sets, average of "best" only?
        - Troposphere only vs. strat + trop models
        - (definition of tropopause)
        - Bulk aerosol properties only, or more detail?

Possible new runs that could be done **post** IPCC AR5:

1) IAMs generate emissions from all four IPCC scenarios (RCPs)
→ Additional simulations using different emissions (i.e. magnitude and time-evolution of emissions) for the same RCP? (aerosols, ozone, methane?).
Note that these are "concentration pathways" for LLGHGs but for short-lived species they aren't concentration pathways but emission pathways. Because of this, different models will give very different results for same stabilization targets.

2) Variation in climate response from:
        a) GCM climate sensitivity
        b) different 3D aerosol fields
        c) aerosol impact on climate (due to location relative to clouds, water uptake, etc.)
→ b) vs c) would give info on aspects controlling forcing

3) Diagnostics:
- Burdens
- Absorbing and reflective AOD both clear- and all-sky radiative forcing by species
    → Issue: Not sufficient for addressing 2) for indirect effect. Additional runs required?

4) Alternative scenarios
- IAMs for IPCC do not emphasize short-lived pollutants (e.g. they have no adverse impact from poor air quality)
- 2100 RF target – tends to de-emphasize doing something about short lived species (i.e. so could reduce BC emissions in 2099 and get impact in 2100…so no economic motivation to reduce in 2025!) How to address this?
- Alternatives from emissions researchers (e.g. IIASA, ANL). However, IIASA 2030 CLE & MFR done, so perhaps low priority.
- Models will be run w/ fixed CO_2 concentrations and then will re-run w/ emissions + carbon cycle (C4 type runs). Look at difference between two. Maybe could do this with methane, as many models now can do methane/climate interactions.

5) We have to be sure that list of simulations does not become excessive! So need to feel out if folks will be willing to do more runs after AR5 runs.

Summary:

→ First and foremost priority is to set up diagnostics for an "AC&C-MIP"

→ Need to determine diagnostics to be saved.

→ Timeline: For models where chemistry and climate are run offline, runs will be done rapidly (6 months) so they can be provided to GCMs. For fully coupled models it's probably more like a year.

Dates of Interest:

2008:

19-21 August: NASA "Measurement Evaluation Panel" meeting (Contact: Gao Chen)
1-5 September: SPARC International Science Conference; Bologna, Italy
7-12 September: IGAC International Science Conference; Annecy, France
8-10 October: AeroCom meeting; Reykjavik, Iceland
13-14 October: HTAP workshop (relationship between intercontinental transport and air quality in the Asian region), Hanoi, Vietnam

2009:
February (date TBD) HTAP workshop (focus on emissions, POPs & mercury); St. Petersburg, Russia
1-5 June: 4th CCMVal workshop, Toronto, Canada
19-29 July: IAMAS/IAPSO/IACS Joint Assembly, Montreal, Quebec, Canada (possibly have an AC&C workshop coordinated with this?)